0-6152: Shear in High-Strength Concrete Bridge Girders

Background

High-strength concrete (HSC), i.e., concrete compressive strength f'_c>8,000 psi, is increasingly being used in highway bridges to enable PC girders of a given size to support larger loads or longer span. Even if it is not specified, it is frequently provided by the contractor to speed concrete strength development. Both shear design provisions in the ACI Code and the AASHTO Specifications are derived empirically for normal strength concrete (up to 8,000 psi) only. Because of their empirical origins and complicated expressions, it is nearly impossible to extend the current design provisions for application to HSC.

Recently, a rational approach was developed at the University of Houston to estimate the maximum shear strength based on the extensive studies of two-dimensional (2D) membrane elements using the universal panel tester available at the University of Houston. Additionally, because the ultimate shear strength increases significantly with increasing the concrete compressive strength, PC I-girders might not reach the maximum shear strength due to shear bond failure, inducing a premature failure. Hence, this research project is divided into two parts.

What the Researchers Did

Part One: Study the Ultimate Shear Strength of the New Tx-Girders as a Function of Concrete Strength

This objective was accomplished by designing, casting, and testing 10 modified Tx28 PC girders using different concrete strengths. The modified cross-section is derived by scaling down Tx54 with an 80-inch-wide top slab by around 43 percent. The girders were divided into three groups (namely Groups A, C, and F) based on the concrete compressive strength. Group A consisted of two girders with a concrete compressive strength of 7,000 psi. Group F had four girders with a concrete compressive strength of 13,000 psi, and Group C included four girders with a compressive strength of 16,000 psi. The study included their behavior at different shear-span-to-depth ratios (a/d) and with different ratios of transverse steel.

A simple and accurate shear design provision that was developed recently at the University of Houston was validated for high-strength concrete based on the experimental results of the 10 Mod. Tx28 I-girders. The new provision consists of three equations. The first equation was derived for the maximum shear strength ($V_{n,max}$) to ensure the yielding of transverse steel before the crushing of concrete. $V_{n,max}$ is a function of the square root of the concrete strength ($\sqrt{f'_c}$) and the web dimensions ($b_w d$). The second equation was derived to predict the "concrete contribution" (V_c), which is also proportional to the square root of the concrete strength ($\sqrt{f'_c}$) and the web dimensions ($b_w d$) and inversely proportional to the shear-span-to-depth ratio $(a/d)^{0.7}$. For the "steel contribution" (V_s) term, the number of transverse steel bars intersecting a 45-degree crack is taken as $(d/s - 1)$.

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The shear behavior of 10 Mod. Tx28 I-girders with different concrete strengths was critically examined with web-shear or flexure-shear failure. From the experimental results of 10 Mod. Tx28 I-girders, the UH equation can accurately predict the ultimate shear strength of PC girders having concrete strength up to 17,000 psi with an adequate ductility. The proposed UH equation is not as overly conservative as the ACI 318 (2011) code provisions. On the other hand, shear design provisions of AASHTO LRFD (2010) code overestimate the ultimate shear strength for PC girders with high-strength concrete.

Also, the experimental results of these I-girders show that the UH equation for predicting the concrete shear contribution (V_c) in a PC girder remains valid for high-strength concrete up to 17,000 psi with different shear-span-to-depth ratios and different ratios of transverse steel.

Finally, the computer program SCS developed recently at the University of Houston using the constitutive models of prestressed concrete derived by the universal panel tester was found to be able to accurately predict the shear behavior of prestressed concrete girders with concrete strength up to 17,000 psi.

Part Two: Study the End Zone Behavior of Different Sizes of Tx-Girders and Effects of Tendon Slip on Web Shear Capacity

Six full-scale prestressed concrete I-girders were designed, cast, and tested. The girders were divided into three groups based on their sizes. Group G consisted of two Tx28 girders. Group D had two Tx46 girders, and Group E included two Tx62 girders. The two girders in each group had a different design as follows.

The first girder in each group was designed and cast with transverse reinforcement according to Texas Department of Transportation (TxDOT) specifications. A top slab with the same width as the top flange was added after tendon releasing. These girders were tested at different shear-span-to-depth ratios (a/d) to check if the studied cross-sections according to current specifications can reach their web shear capacities without having a shear bond failure.

The second girder in each group was designed and cast according to AASHTO-specified minimum transverse reinforcement to check the minimum web shear capacity of the end zone. The conclusions for part two are summarized below.

The experimental data show that the Tx-girders designed according to TxDOT current specifications have no cracks under service loads. The tested girders—either according to TxDOT current design specifications or with the minimum transverse reinforcement according to AASHTO LRFD (2010)—have no shear bond failure.

The experimental results of the six PC I-girders show that the UH equations for predicting the ultimate shear strength and the concrete shear contribution are not affected by the girder size. Both remain applicable for girders with different depths and web-depth-to-thickness ratios. The computer program SCS developed recently at the University of Houston using the constitutive models of prestressed concrete derived by the universal panel tester was found applicable to prestressed concrete girders with depths up to 70 inches under monotonic loads.

For More Information

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